Lawrence Berkeley National Laboratory

Department of Energy BENEFIT FOA Award 1027-1682

A New Hybrid Approach to Energy Modeling

Task 5: Demonstration and validation of the hybrid model in the FLEXLAB

Deliverable:
Validation of the Hybrid Modeling Using Measured Data from the FLEXLAB Experiment

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July 31, 2016

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1 Introduction

The hybrid modeling is a new modeling method to enhance the accuracy of the building energy simulation for existing buildings. The hybrid modeling approach replaces highly uncertain inputs such as interior thermal mass and infiltration air flow rate with easily measurable data (e.g., zone air temperature) as new inputs in energy simulations. The hybrid modeling method is built upon the physics-based model and taking advantage of more widely available data streams from smart devices such as smart thermostats in buildings. The hybrid modeling approach derives physical characteristics of the interior thermal mass and infiltration by inversely solving the zone heat balance equations using the measured zone air temperatures. The hybrid model was implemented, tested and validated in a custom branch of EnergyPlus.

The experiment using LBNL's Facility for Low Energy Experiment in Buildings (FLEXLAB) is part of the project for demonstration and validation of the hybrid modeling approach. This deliverable provides validation results of the hybrid modeling approach using the measured data from the FLEXLAB experiment. The validation uses the measured zone air temperature to inversely calculate the zone interior mass (IM) multiplier and zone air infiltration rate by using the hybrid model implemented in EnergyPlus. A guideline is also provided on the use of the hybrid model implemented in EnergyPlus.

2 FLEXLAB Experiment

The experiment was conducted at the FLEXLAB testbed cell 3A (Figure 1) for 50 days from April 4 to May 23 in 2016. The cell 3A is 57 m^2 (612 ft^2) designed to meet ASHRAE 90.1-2010 code requirements. The experiment simulated internal heat loads (Figure 2) of 1200 watt, in typical office spaces, with three designated portable electric heaters (750 Watt, 150 Watt, 150 Watt) and two air mixing fans (each 75 Watt). The operation schedule of the electric heaters was programmed to be on between 8am and 6pm and off for other hours. The air mixing fans were programmed to operate for 24 hours to ensure well mixing of zone air during the whole experiment. The HVAC system is off all the time, so there is no space cooling or heating from the HVAC system.

Figure 1 Exterior View of the FLEXLAB Testbed Cell 3A

The measurement of the cell 3A's indoor air temperature under various infiltration air flow rates and internal mass configurations was the key of the experiment. A total of 28 temperature sensors were used to measure the indoor air temperature. Four stratification sensor trees each with seven sensors were located at each corner of the cell space. Each tree (Figure 3) has seven temperature sensors placed in an equal distance from floor to ceiling. The sensor data were stored in sMAP (Simple Measurement and Actuation Profile) system and one-minute interval sensor data were provided via the FLEXLAB sMAP web interface (https://flexstorevh.lbl.gov). Figure 3 shows an example of the measured temperature data from the 28 temperature sensors for three days. The accurate sensor data were critical as the measured data (indoor air temperature, electric power of the heaters, and infiltration air flow rates) were used to validate the hybrid model.

Figure 2 Electric equipment to generate controlled internal heat gains

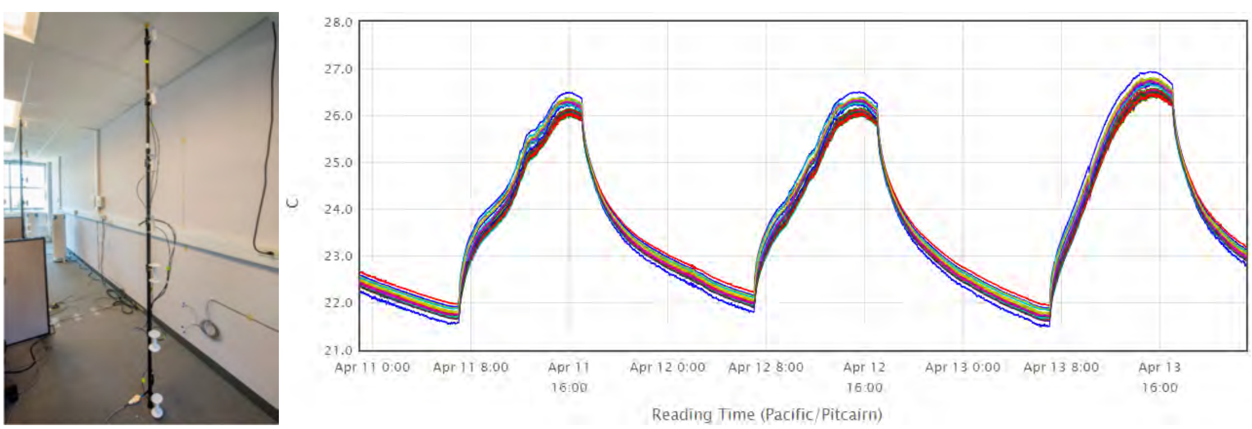

Figure 3 Stratification sensor tree to measure zone air temperature

The experiment conducted tests to measure the air temperatures under a range of interior configurations of light and heavy internal mass, and tight and leaky air infiltration. The initial experiment design covered combinations of three levels of internal mass and four infiltration rates conditions. Table 1 shows the initial plan for the experiment with the configuration of internal mass and infiltration rates.

Table 1 Initial Experiment Plan

Test ID	Estimated Period	Internal Mass Design	Infiltration Design
Setup	4/4 Mon - 4/5 Tue	Experiment preparation, locate sensors, install and check fan for controlled outside air supply	
LM.0	4/6 Wed - 4/9 Sat	Light (typical office setting)	0.17 ach, as-built
LM.1	4/10 Sun - 4/13 Wed		0.5 ach, constant
LM.2	4/14 Thur - 4/17 Sun		5 ach, constant
LM.3	4/18 Mon - 4/21 Thur		1 - 5 ach, scheduled
HM.0	4/22 Fri - 4/25 Mon	Heavy (with added books)	0.17 ach, as-built
HM.1	4/26 Tue - 4/29 Fri		0.5 ach, constant
HM.2	4/30 Sat - 5/3 Tue		5 ach, constant
HM.3	5/4 Wed - 5/7 Sat		1 - 5 ach, scheduled
NM.0	5/8 Sun - 5/11 Wed	No internal mass (empty space)	0.17 ach, as-built
NM.1	5/12 Thur - 5/15 Sun		1 ach, constant
NM.2	5/16 Mon - 5/19 Thur		5 ach, constant
NM.3	5/20 Mon - 5/23 Mon		1 - 5 ach, scheduled

The experiment design configurations of the internal mass and infiltration rate are as follows:

- Internal mass:
    - Light mass (LM) represents a very light office configuration with six set of light-mass desks, chairs, cotton manikins, desktop computers, and monitors (Figure 4)
    - Heavy mass (HM) represents a heavy office configuration (For experiment about 1000 library books in 50 boxes are added to the cell space) (Figure 5)
    - No mass (NM) represents an empty space (no furniture or partitions)
- Infiltration air flow rates:
    - Tight infiltration rate: 0.17 ach, a natural cell condition with door closed and air dampers closed
    - Medium infiltration rate: 0.5 ach controlled with a designated exhaust fan
    - High infiltration rate: 5 ach controlled with a designated exhaust fan
    - Infiltration with schedule: 0.25 ach (6am – 10pm) and 1 ach (10 pm – 6am) controlled with a designated exhaust fan

The fan was installed nearby the exhaust grill in the plenum space (Figure 6) to control the exhaust air flow rates. The experiment designed the amount of the exhaust air to introduce the same amount of the outdoor air through supply duct with an open damper and door and window gap. The heating, ventilation, and air conditioning (HVAC) system was off during the whole experiment.

Figure 4 Experiment cell space showing a typical light office configuration representing the light internal thermal mass

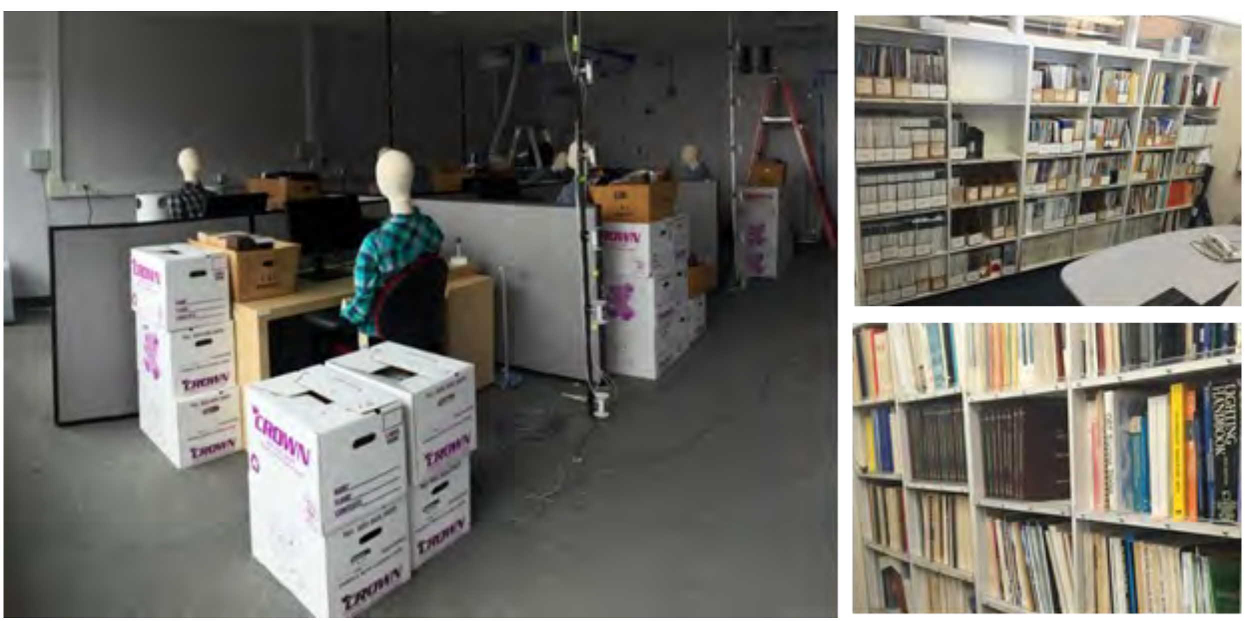

Figure 5 Experiment cell space showing an office configuration with added books representing the heavy internal thermal mass, about 1000 books in BTUS division library were moved to the cell.

During the course of the experiment with the initial plan, unexpected air leaks were observed in the plenum space. The controlled amount of the outside air was crucial for the experiment success, but we found that the air leak from the plenum space was causing the cell space air change rate uncontrolled. The fan (Figure 6: left) was installed on the exhaust grill in the plenum. The increased fan pressure brought uncontrolled air from the leaks in the plenum space, which caused less outside air coming into the cell space. The measured outside air volume (ach) did not meet the experiment design systematically with the experiment design. The problem was critical for the experiment, and the management team decided to stop the experiment and reconfigure the design of the experiment. To resolve the problem, we replaced the exhaust fan inside the room space and sealed ceiling tiles to minimize leaks from the plenum (Figure 6 right). Then the measurement data gets close to the design.

Figure 6 Exhaust fan to control infiltration air flow rate (left: before and right: after)

The CO_2 tracer gas decay testing method is used to measure the infiltration air flow rate. The approach has been used widely to measure outdoor air change rates with standard methods of tests (ASTM, 2011; ISO, 2012). Figure 7 shows CO_2 gas release and infiltration air flow converted to air change per hour (ach) results, for the 0.5 ach case. After moving the exhaust fan to the cell space and sealing the ceiling tiles and doors, we could get the measurement of the air change rate as designed.

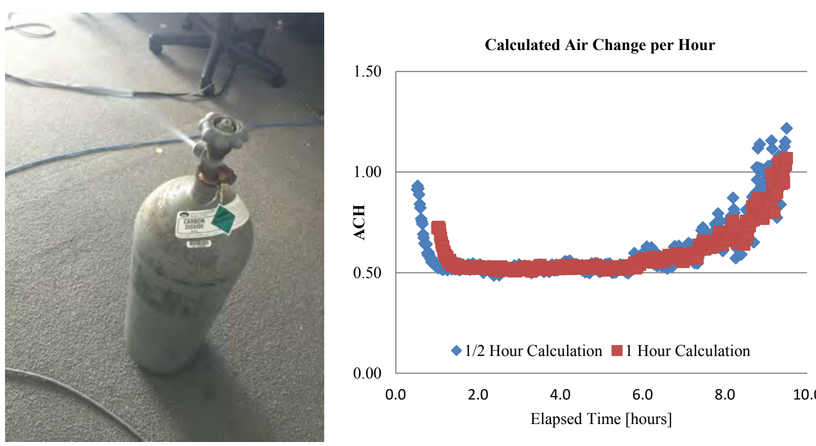

Figure 7 Measurement of the outside air change using CO2 tracer gas system (Left: CO2 gas release and right: ach calculation results e.g. 0.5 ach)

It took five days for the problem inspection and experiment reconfiguration. The experiment resumed on April 27. Because of the limited experiment timeline and resources, we had to adjust the experiment plan by canceling the no internal mass tests, and reallocated the experiment as shown in Table 2. The grayed rows indicate the tests that were not controlled due to invalid data. The design of the infiltration rates was reconfigured for more precise control of the outside air change rates reflecting the experiment condition and practical infiltration rates in existing buildings.

Table 2 Design of the Experiment after Inspection

Test ID	Experiment Period	Internal Mass Design	Infiltration Design	Note
LM.0	4/6 Wed - 4/9 Sat	Light	0.17 ach, as-built	Uncontrolled data
LM.1	4/10 Sun - 4/13 Wed	Light	0.42 ach, constant	
LM.2	4/14 Thur - 4/17 Sun	Light	1.5 ach, constant	Uncontrolled data
LM.3	4/18 Mon - 4/21 Thur	Light	0.25 - 1 ach	Uncontrolled data
Inspection	4/22 Fri - 4/26 Tue	Measured ach did not match the designed ach. Fan and controller broken, air leak from the plenum space		
LM.2	4/27 Wed - 4/30 Sat	Light	2 ach, constant	
LM.3	5/1 Sun - 5/3 Tue	Light	0.18 – 0.7 ach	
HM.3	5/4 Wed - 5/7 Sat	Heavy	0.18 – 0.7 ach	5/4 Wed: placed books in FLEXLAB
HM.2	5/8 Sun - 5/11 Wed	Heavy	2 ach, constant	
HM. 1	5/12 Thur - 5/15 Sun	Heavy	0.42 ach, constant	
HM.0	5/16 Mon - 5/19 Thur	Heavy	0.17 ach, as-built	
LM.0	5/20 Fri - 5/23 Mon	Light	0.17 ach, as-built	5/20 Fri: removed books from FLEXLAB

Figure 8 shows the infrared images of the experiment cell. Top images illustrate the heat emitted to the space using electric heaters and the bottom ones show cold air introduced to the space by infiltration. The left one is the entrance door, which shows a significance of the heat transfer from the direct infiltration through door gaps. The right one is the door to a mechanical closet indicating unwanted cold air introduced to the cell, which is a significant heat loss.

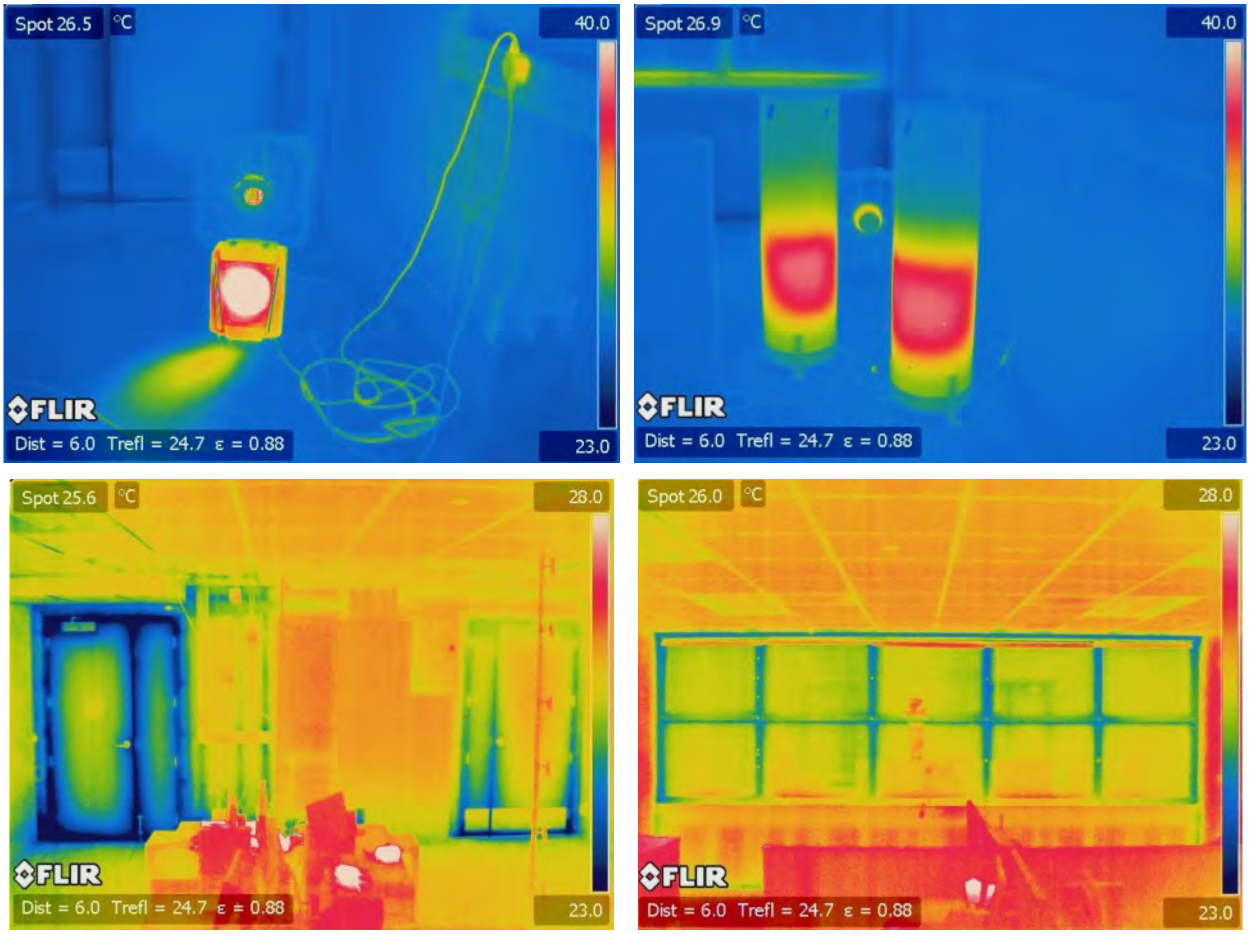

Figure 8 Infrared images of 750W heater (top left), two 150W heaters (top right), entrance and mechanical closet door (bottom left, and windows (bottom right)

After the experiment, we extracted the measured data from the sMAP system and processed them for the validation. The measured data include:

- Zone air temperature from the 28 sensors (four stratification trees, each with seven temperature sensors)
  - The average temperature of 20 sensors is used as the zone air temperature data.
    NOTE: The top (underneath the ceiling tile) and bottom (above the floor) temperature sensors for each stratification tree were excluded from the average calculation.
- Electric power from individual outlets for electric heaters, air mixing fans, exhaust air fan, and control systems (computers, sensor connection hubs)
- CO_2 PPM decay data for zone ach calculation
- Outside air inlet temperature
- Interior wall surface temperature
- Floor slab temperature
- Weather data
  - outdoor air dry bulb temperature
  - solar global irradiation
  - solar diffuse radiation
  - wind speed

3 Calibration of the FLEXLAB EnergyPlus Model

3.1 The Energy Model of the FLEXLAB

LBNL BTUS Division maintains EnergyPlus models and weather data to support FLEXLAB experiment users.

Figure 9 shows screenshots of the Testbed 3 EnergyPlus model. We updated the energy model to reflect the FLEXLAB experiment, adding the ideal load air system as the FLEXLAB tests were designed to measure the free floating zone air temperature. The internal heat gain input data was obtained from the electric heaters. The infiltration design air flow input data were from the measurement data of CO_2 tracer gas tests and the air flow meter. Table 3 shows the EnergyPlus inputs, with their values derived from the experiment results.

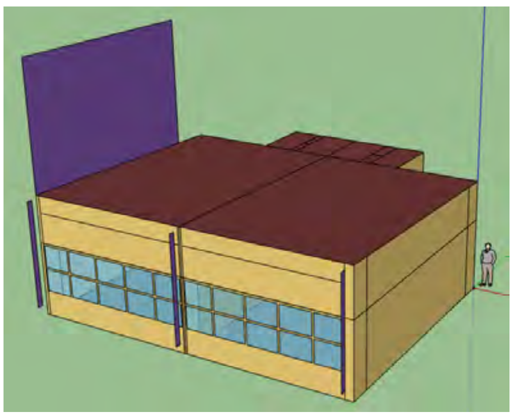
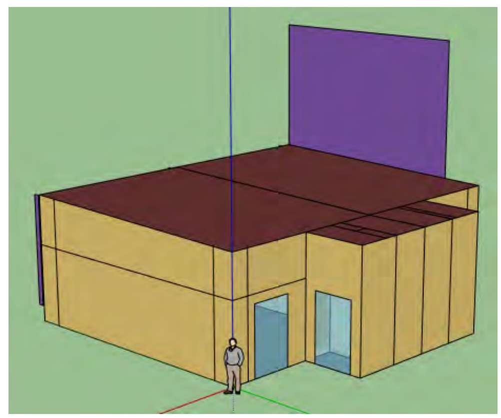

Figure 9 Schematic view of the EnergyPlus model for the FLEXLAB Testbed 3

Table 3 FLEXLAB EnergyPlus Model Input Values from Experiments

	Electric Equipment [Watt]	Electric Equipment Schedule	Infiltration ach	Infiltration Schedule
Level.0	1,234	0-8: 0.15, 8-18: 1.00, 18-24: 0.15	0.1	0-24: 1.00
Level.1	1,261	0-8: 0.17, 8-18: 1.00, 18-24: 0.17	0.42	0-24: 1.00
Level.2	1,379	0-8: 0.24, 8-18: 1.00, 18-24: 0.24	2.0	0-24: 1.00
Level.3	1,338	0-6: 0.20, 6-8: 0.16, 8-18: 1.00, 18-22: 0.16, 22-24: 0.20	0.7	0-6:1.00, 6-22: 0.25, 22-24:1.00

3.2 Model Calibration

We used the exhaust fan to control the infiltration air flow. The installed fan was designed to control the amount of the direct exhaust air through the exhaust duct. The experiment left dampers open in the supply duct allowing the outside air introduced through the supply duct with equal amount of the exhaust air. However, it turned out that the introduced air through the supply duct picked up heat when outside air is colder than the surrounding duct temperature. The outside air travels about 15m distance passing through the air handling unit located in the mechanical closet and duct laid out in the mechanical closet and plenum space. Thus, it needed special efforts to consider the heat added or removed from the air entering the cell space.

The infiltration inputs for the outside air are added to the “ZoneInfiltration:DesignFlowRate” EnergyPlus IDD object. The air flow rate input is for the direct heat transfer between outdoor air and zone air, which does not reflect heat added or removed in the infiltration air in each timestep. Although the FLEXLAB experiment carefully designed the amount of the air exchange between indoor and outdoor, the introduced air temperature to the internal space could not be the same as the outdoor air temperature. The significant amount of the entering air from the supply duct picked up heat when traveling. Also the infiltration air from cracks in the ceiling tiles and mechanical closet could not be ignored, which leads to the entering air temperature different from the outside air temperature. Thus, we used “ElectricEquipment” EnergyPlus object to compensate the unwanted heat added to or removed from the infiltration air.

Another important parameter is the IM multiplier for the light mass and heavy mass cases. The light mass test cases represent very light office furniture environment with six set of light office desks, chairs, cotton manikins, desktop computers, and monitors. The heavy mass test cases have about 1000 library books in 50 boxes added to the existing light mass office layout. To capture these internal mass for different office configurations, we tested various internal mass multipliers in EnergyPlus object, ZoneCapacitanceMultiplier:ResearchSpecial. The best matching multipliers for these two conditions were:

- Light mass (LM) cases: IM multiplier of 3
- Heavy mass (HM) cases: IM multiplier of 5

Figure 10 (light mass) and Figure 11 (heavy mass) show the results of the calibration for each test cases presenting the indoor measured and simulated air temperature. Each test case has three days of the measured air temperature data with black solid lines, and the red dotted lines represent the simulated zone air temperatures.

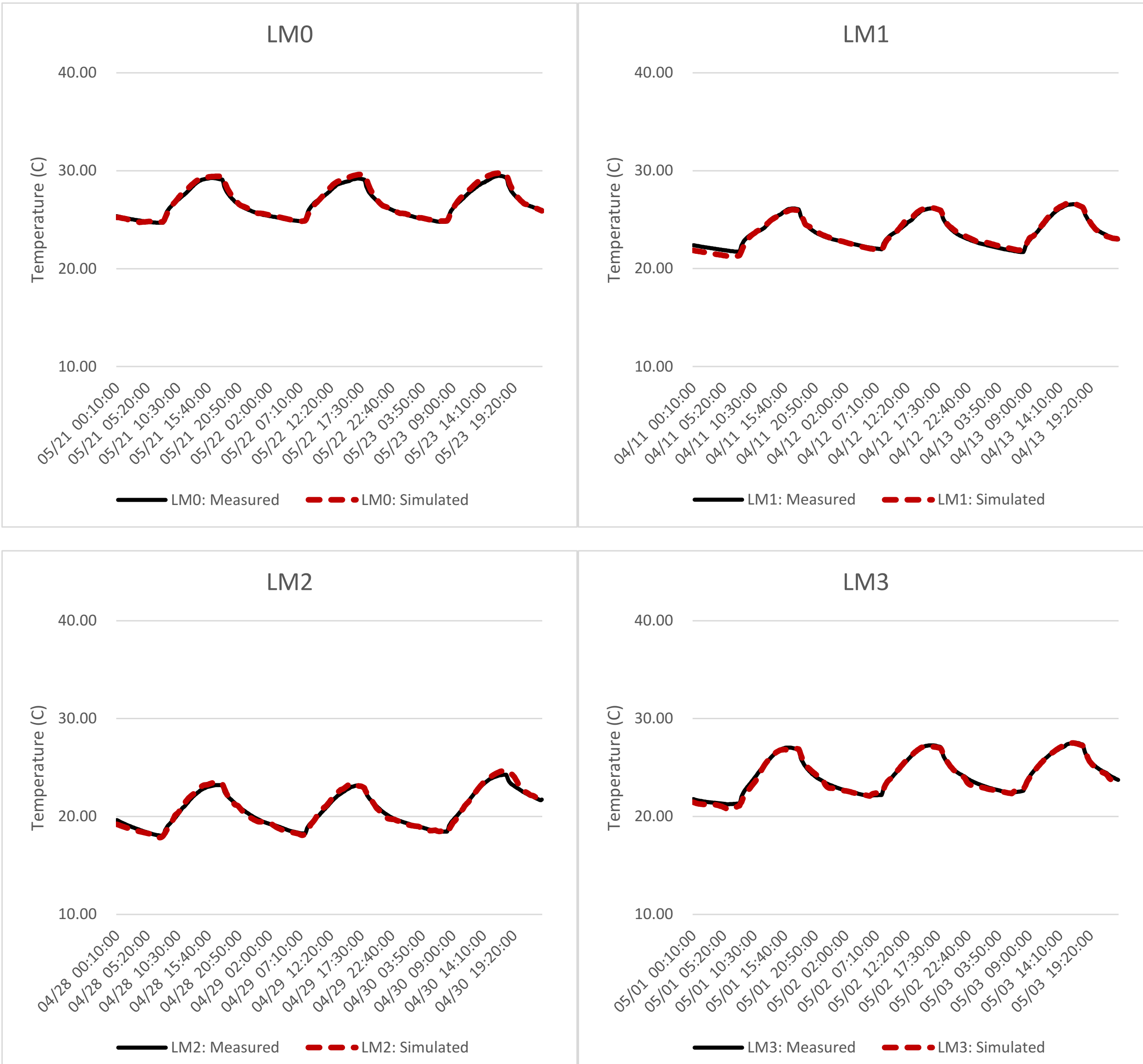

Figure 10 The Calibrated EnergyPlus Model Zone Air Temperature Compared to the Measured Zone Air Temperature for the Low Mass Experiment Cases

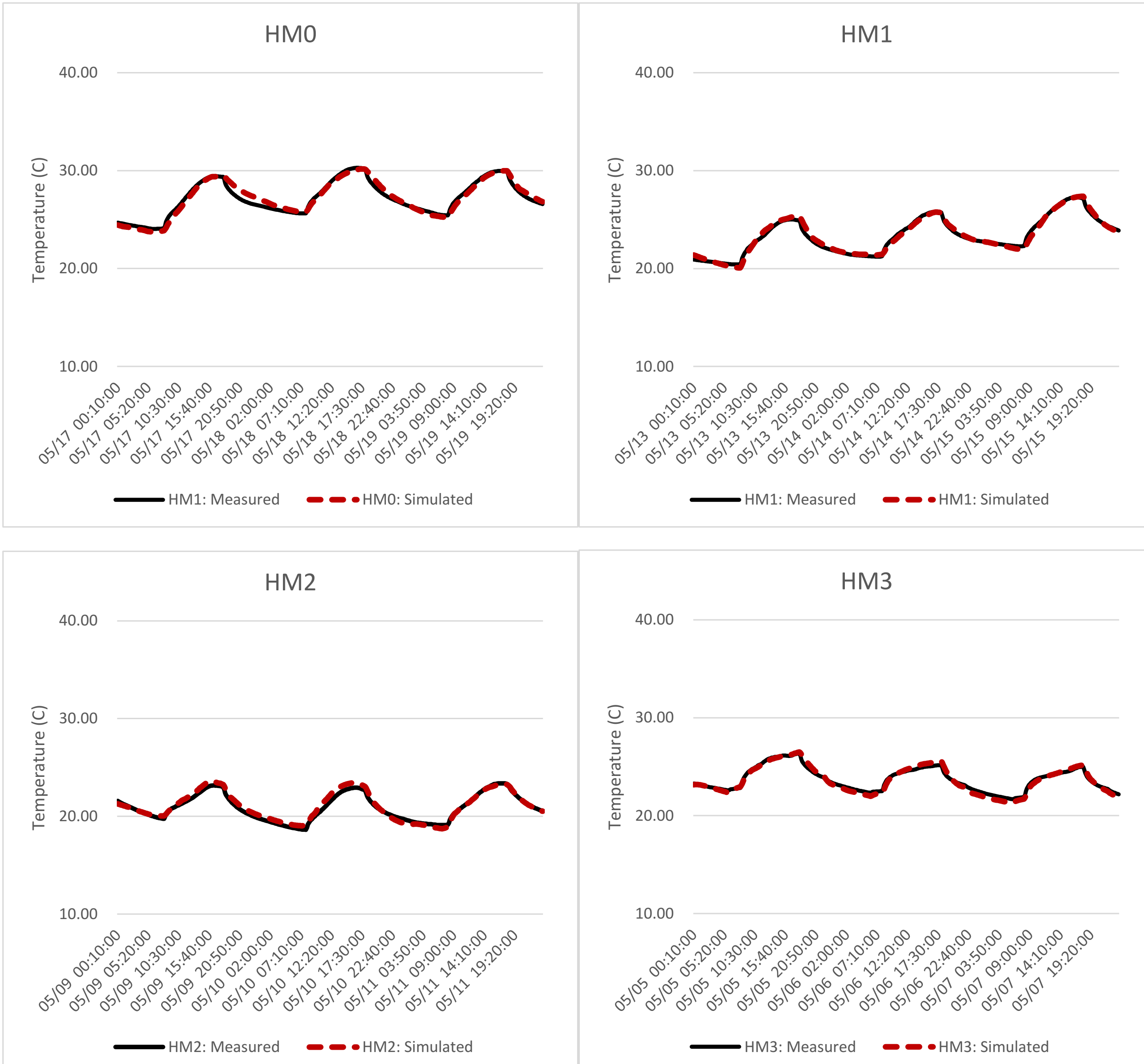

Figure 11 The Calibrated EnergyPlus Model Zone Air Temperature Compared to the Measured Zone Air Temperature for the Heavy Mass Experiment Cases

Table 4 shows the Normalized Mean Bias Error (NMBE) and Coefficient of Variance of Root Mean Square Error (CVRMSE) between two sets of monthly or hourly results, which are commonly used to determine the goodness of fit between the simulation results and measured data. Two sets of results agree with each other very well. The NMBE and CVRMSE are no greater than 2% for the 10-minute timestep results, which shows the calibrated models very well represented the experiment cases.

Table 4 Zone Air Temperature from the Calibrated EnergyPlus Model Compared to the Measured Air Temperature

	LM0	LM1	LM2	LM3	HM0	HM1	HM2	HM3
NMBE	0.50%	-0.03%	0.13%	-0.33%	0.12%	0.10%	0.68%	-0.26%
CVRMSE	0.85%	0.99%	1.20%	0.82%	1.45%	1.11%	1.50%	1.08%

4 Validation of the Hybrid Modeling Results

There are two parts of the validation conducted for the hybrid model implemented in EnergyPlus. First, we validated the hybrid model using the simulated zone air temperature data from the calibrated EnergyPlus model. Then further validation was done using the measured zone air temperature and infiltration data from the FLEXLAB experiment.

4.1 Validation using the Simulated Zone Air Temperature

The 10-minute interval zone air temperature data were generated using the calibrated energy models, then the temperature data were used to derive the infiltration air flow rate and IM multiplier using the hybrid model implemented in EnergyPlus.

Table 5 shows the summary of the hybrid modeling calculation results that used the simulated zone air temperature for each test case. Further details of the hybrid model simulation results are presented in Figure 12 to Figure 15 for the low internal mass cases, and in Figure 16 to Figure 19 for the heavy internal mass cases. Each figure includes the calculated infiltration ach and IM multipliers for each timestep. The black rectangular box indicates the three-day test period for the different experiment configurations.

The inverse calculation of the infiltration using the hybrid model simulation provides estimates of the original input values in the energy model. The IM multipliers have about 20% of deviation from the original input values. For the internal mass calculation using the hybrid model, it needs to have enough time for indoor air temperature to stabilize due to interactions of the cell structure with the dynamic environmental conditions. From the validation study, it is recommended to have seven days for the hybrid model simulation in order to calculate the zone internal thermal mass multipliers.

Table 5 Calculated Infiltration and IM Multiplier using the Simulated Zone Air Temperature

	Infiltration				***Internal Mass Multiplier***			
	Energy Model Input	Calculated using ***Simulated*** Air Temperature			Energy Model Input	Calculated using ***Simulated*** Air Temperature		
		2 months average	1 week average	3 days average		2 months average	1 week average	3 days average
Figure 12: LM0	0.10	0.10	0.10	0.10	3.00	3.22	3.25	3.30
Figure 13: LM1	0.42	0.42	0.42	0.42	3.00	3.27	3.34	3.58
Figure 14: LM2	2.00	2.00	2.00	2.00	3.00	3.51	3.53	3.55
Figure 15: LM3	0.7 nighttime, 0.18 daytime	0.7 nighttime, 0.17 daytime	0.7 nighttim e, 0.18 daytime	0.7 nighttim e, 0.18 daytime	3.00	3.19	3.23	3.32
Figure 16: HM0	0.10	0.10	0.10	0.10	5.00	5.29	5.26	5.21
Figure 17: HM1	0.42	0.42	0.42	0.42	5.00	5.28	5.24	5.18
Figure 18: HM2	2.00	2.00	2.00	2.00	5.00	5.56	5.51	5.41
Figure 19: HM3	0.7 nighttime, 0.18 daytime	0.7 nighttime, 0.17 daytime	0.7 nighttim e, 0.17 daytime	0.7 nighttim e, 0.17 daytime	5.00	5.21	5.18	5.09

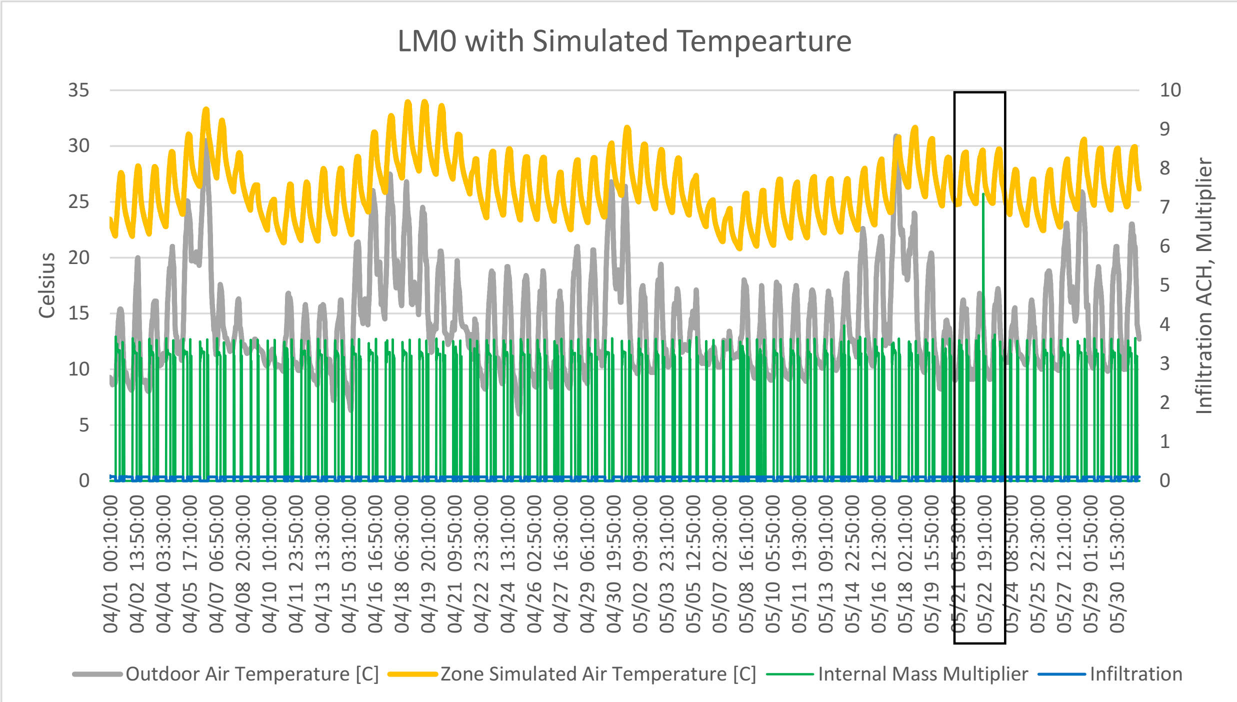

Figure 12 The Calculated Infiltration and Internal Mass Multiplier for the LM0 Experiment Case using the Simulated Zone Air Temperature

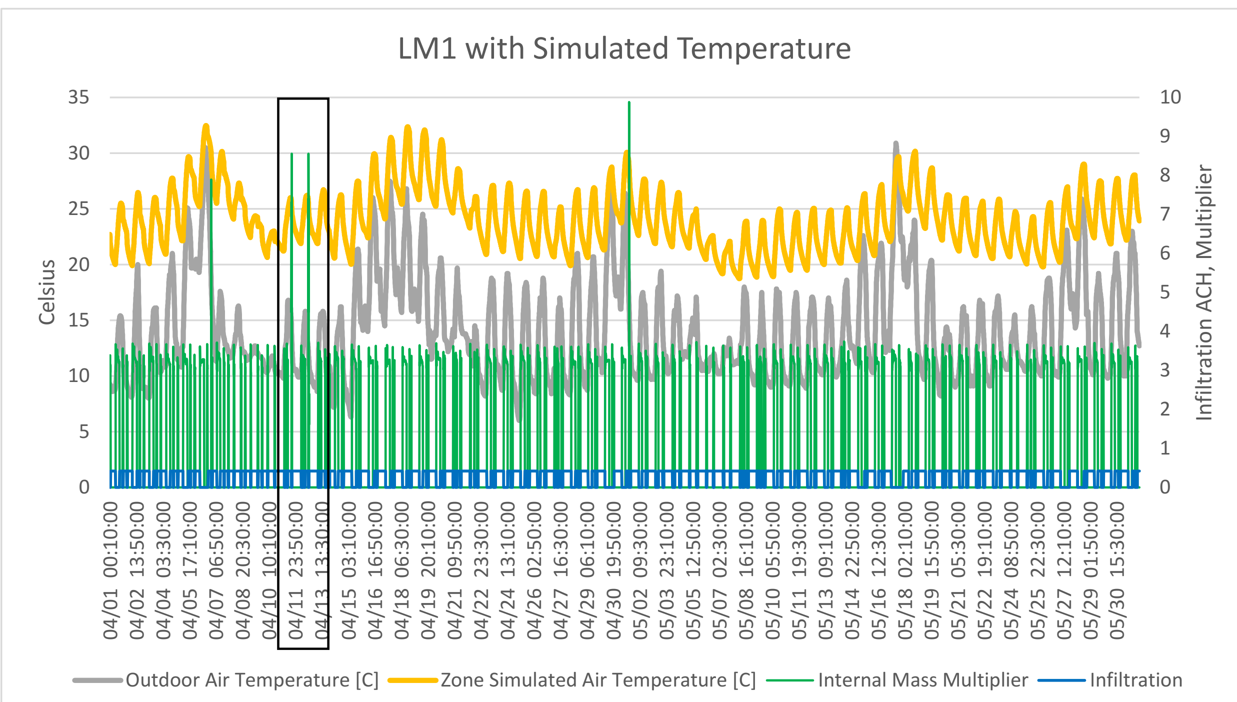

Figure 13 The Calculated Infiltration and Internal Mass Multiplier for the LM1 Experiment Case using the Simulated Zone Air Temperature

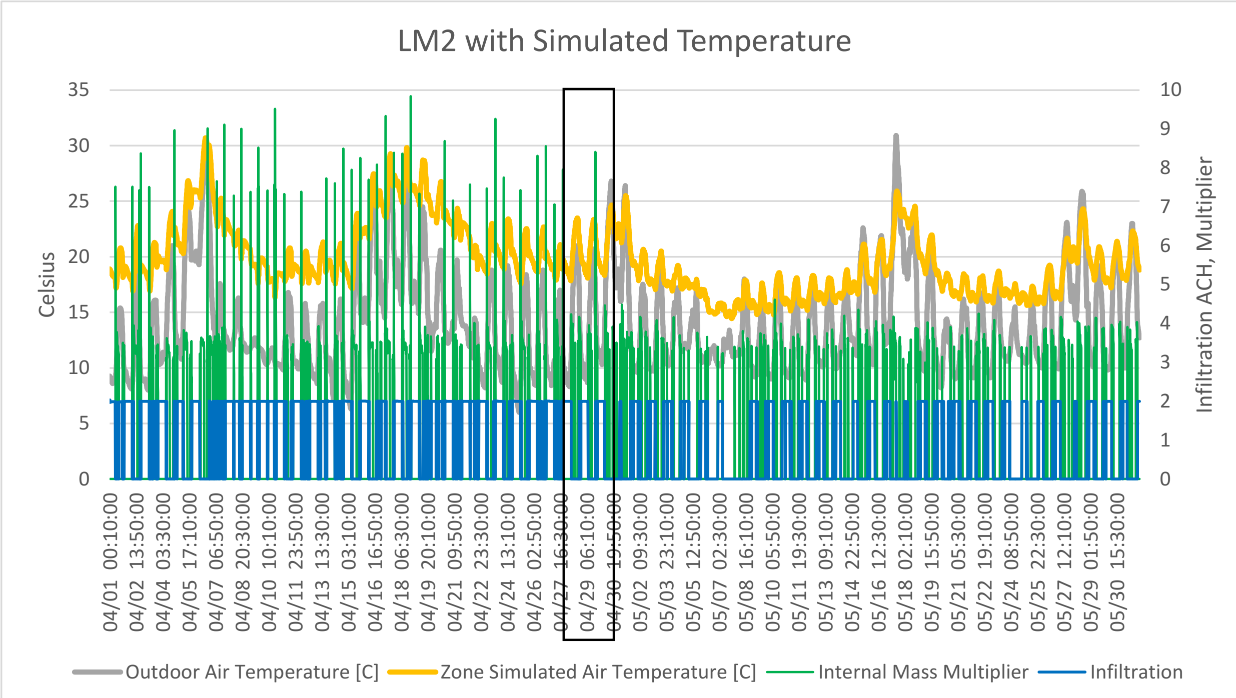

Figure 14 The Calculated Infiltration and Internal Mass Multiplier for the LM2 Experiment Case using the Simulated Zone Air Temperature

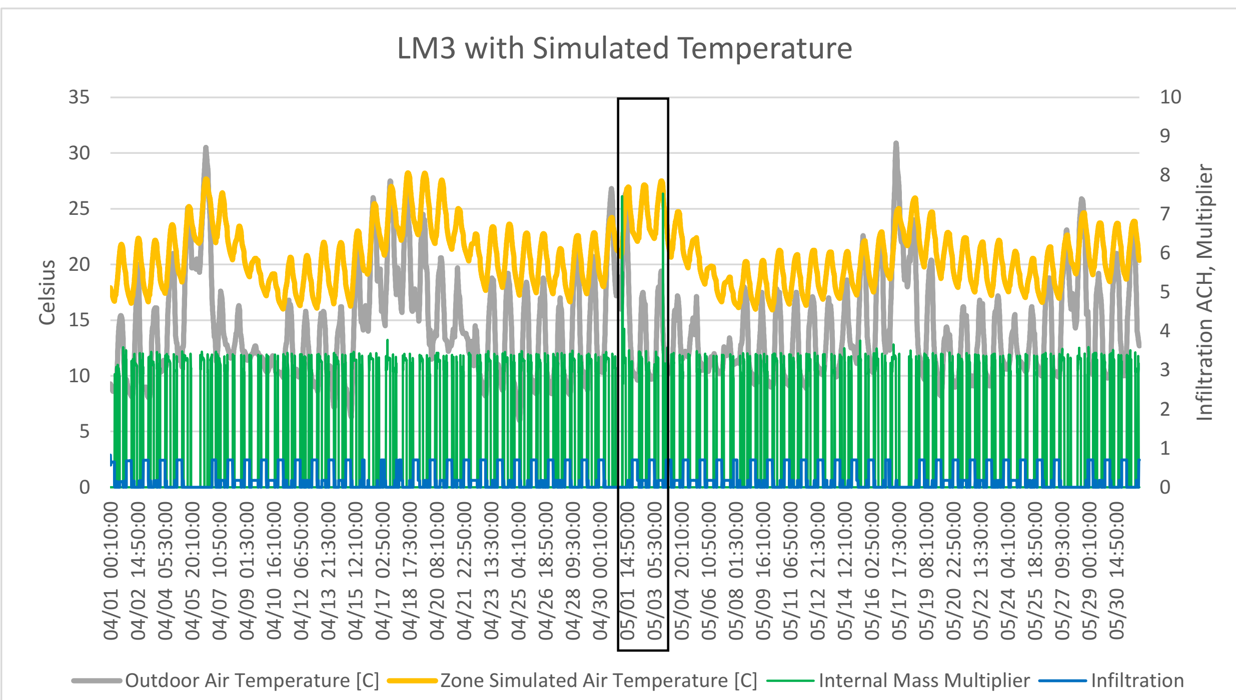

Figure 15 The Calculated Infiltration and Internal Mass Multiplier for the LM3 Experiment Case using the Simulated Zone Air Temperature

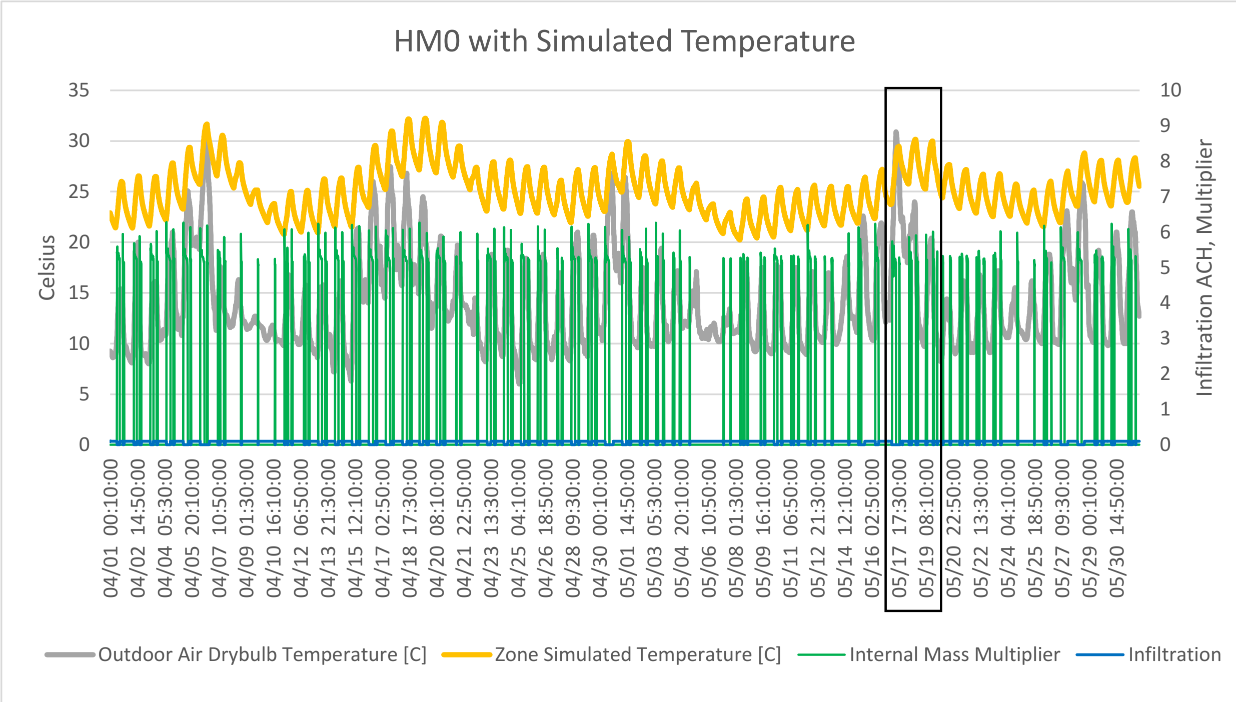

Figure 16 The Calculated Infiltration and Internal Mass Multiplier for the HM0 Experiment Case using the Simulated Zone Air Temperature

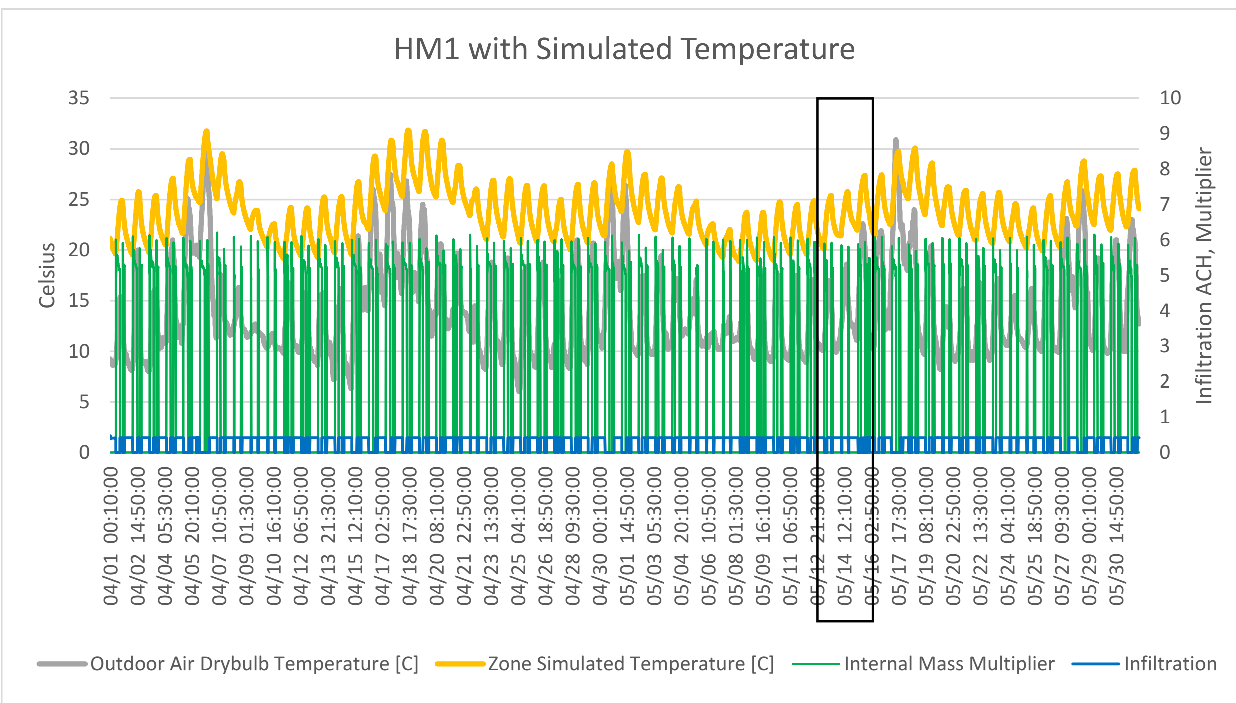

Figure 17 The Calculated Infiltration and Internal Mass Multiplier for the HM1 Experiment Case using the Simulated Zone Air Temperature

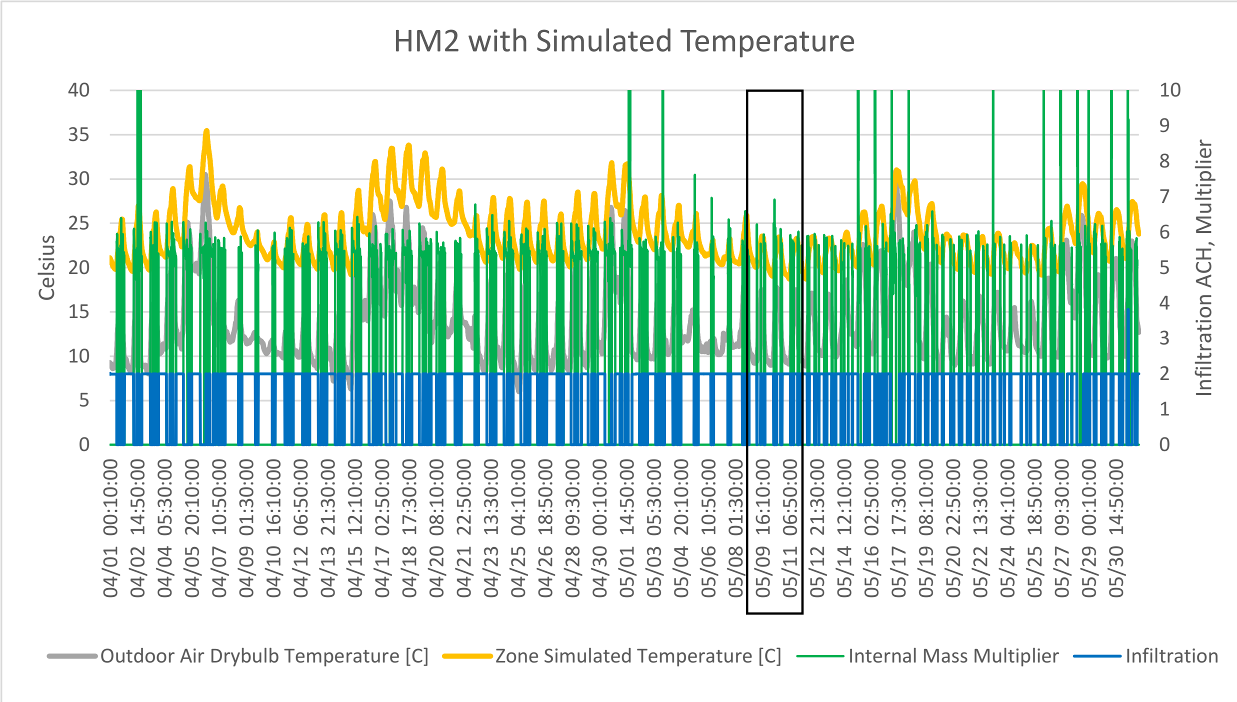

Figure 18 The Calculated Infiltration and Internal Mass Multiplier for the HM2 Experiment Case using the Simulated Zone Air Temperature

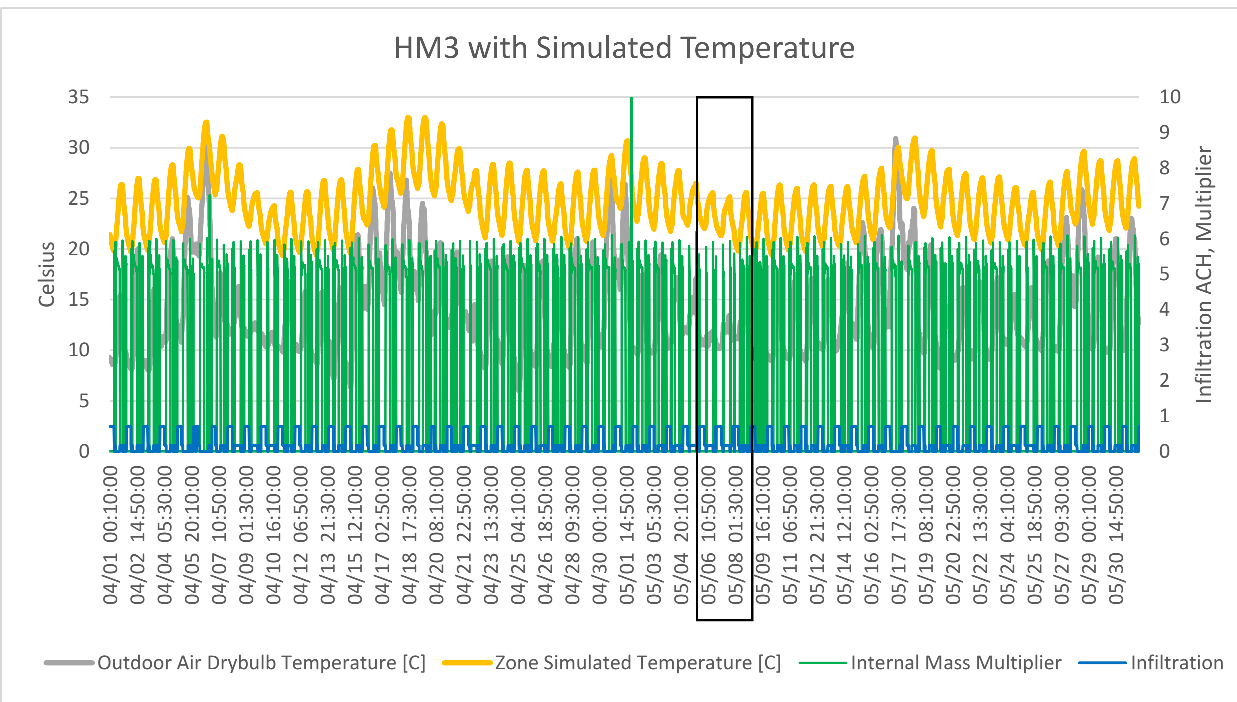

Figure 19 The Calculated Infiltration and Internal Mass Multiplier for the HM3 Experiment Case using the Simulated Zone Air Temperature

4.2 Validation using the Measured Zone Air Temperature

This section provides details of the validation of hybrid modeling using the measured zone air temperature from the FLEXLAB experiment. First of all, we replaced three-day temperature data (marked as black rectangular boxes in charts for each test case presented in Section 4.1) with the measured temperature data. For each test case, seven days of the temperature data were prepared, which is composed of the three days of actual measured data and four days of simulated temperature data. As the experiment for each test case is limited to only three days, the hybrid model simulation added the simulated temperature data for a period of four extended days. This one week temperature data were used to derive the infiltration air flow rate and IM multiplier under the hybrid modeling simulation mode.

Table 6 shows the summary of the hybrid modeling calculation results that used the simulated zone air temperature for each test case. The table presents the average calculated infiltration and IM multipliers with the measured temperature data of three days as well as the seven-day temperature data. Further details of the hybrid modeling simulation results are presented in Figure 20 to Figure 23 for the low internal mass cases, and in Figure 24 to Figure 27 for the heavy internal mass cases. Each chart includes the calculated infiltration rate (ach) and IM multipliers for each timestep. The black rectangular box indicates the three-day test period. It is observed that there are noises in the calculated infiltration air flow rates and IM multipliers for the period where the measured zone air temperature data were used. This is caused by the fact that the measured air temperature is not the same as the simulated air temperature. Although the calibrated model reflects the dynamics of the indoor environment as represented in the measured air temperature (very small NMBE and CVRMSE), even the minor difference of the zone air temperature brings uncertainties to the model parameters. This causes the infiltration air flow and IM multiplier to be a result of other dynamic conditions. Also it tells that the measured zone air temperature for three days are not enough to derive parameter values accurately.

Table 6 The Calculated Infiltration and IM Multiplier using the Measured Zone Air Temperature

	Infiltration			Internal Mass Multiplier		
	Energy Model Input	Calculated using ***Measured*** Air Temperature		Energy Model Input	Calculated using ***Measured*** Air Temperature	
		1 week average	3 days average		1 week average	3 days average
Figure 20: LM0	0.10	0.11	0.13	3.00	3.24	3.33
Figure 21: LM1	0.42	0.42	0.42	3.00	3.32	3.53
Figure 22: LM2	2.00	1.97	1.93	3.00	3.92	4.53
Figure 23: LM3	0.7 nighttime, 0.18 daytime	0.69 nighttime, 0.18 daytime	0.66 nighttime, 0.19 daytime	3.00	3.17	3.23
Figure 24: HM0	0.10	0.10	0.10	5.00	4.90	3.60
Figure 25: HM1	0.42	0.42	0.42	5.00	4.99	4.04
Figure 26: HM2	2.00	2.02	2.05	5.00	5.70	5.98
Figure 27: HM3	0.7 nighttime, 0.18 daytime	0.65 nighttime, 0.19 daytime	0.7 nighttime, 0.17 daytime	5.00	5.07	4.20

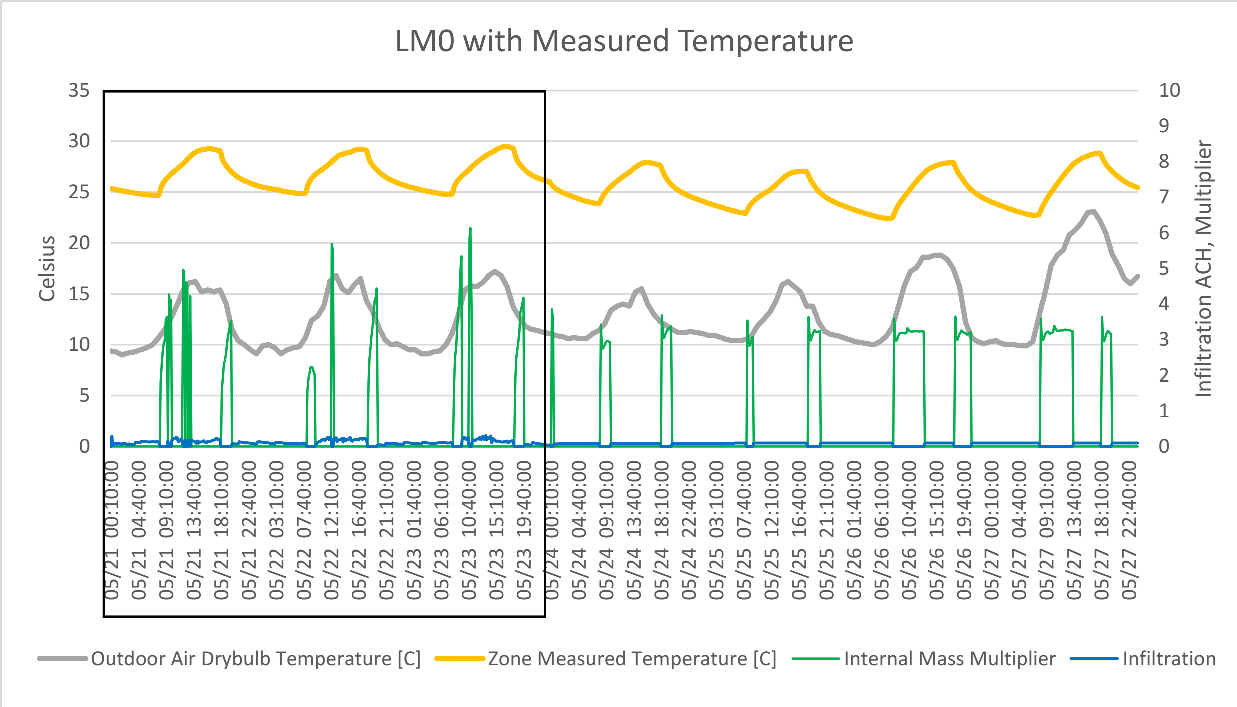

Figure 20 The Calculated Infiltration and Internal Mass Multiplier for the LM0 Experiment Case using the Measured Zone Air Temperature

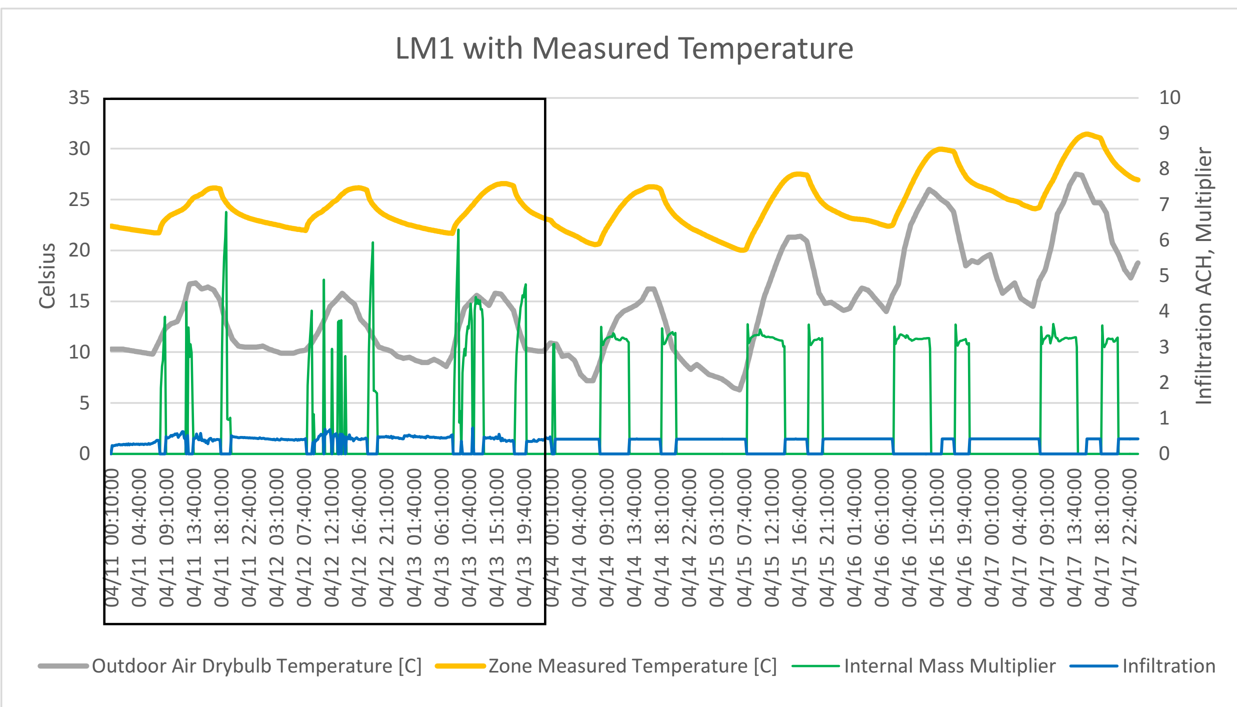

Figure 21 The Calculated Infiltration and Internal Mass Multiplier for the LM1 Experiment Case using the Measured Zone Air Temperature

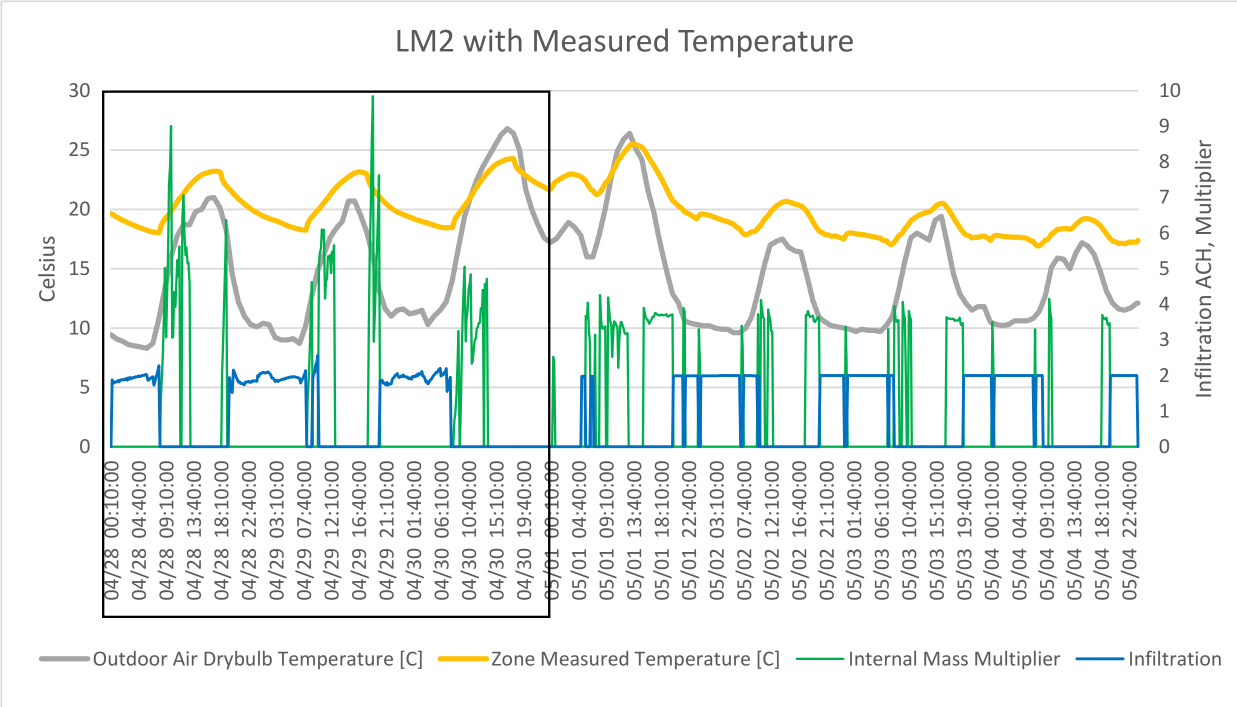

Figure 22 The Calculated Infiltration and Internal Mass Multiplier for the LM2 Experiment Case using the Measured Zone Air Temperature

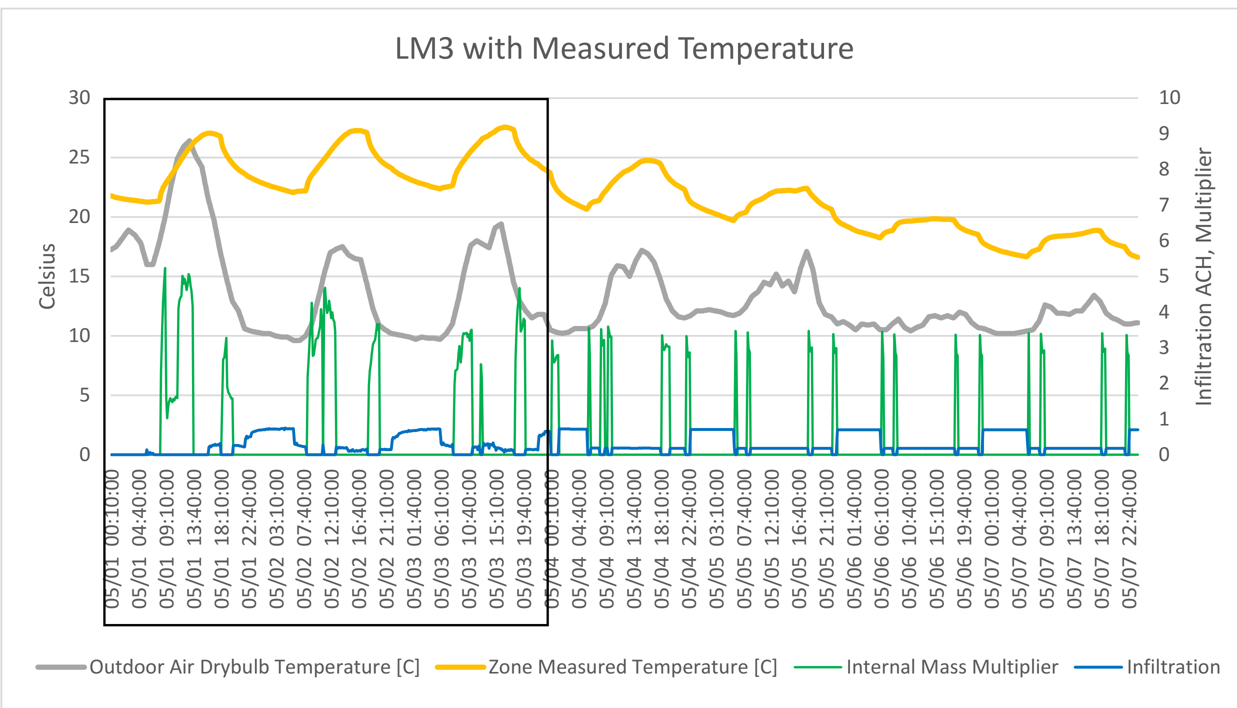

Figure 23 The Calculated Infiltration and Internal Mass Multiplier for the LM3 Experiment Case using the Measured Zone Air Temperature

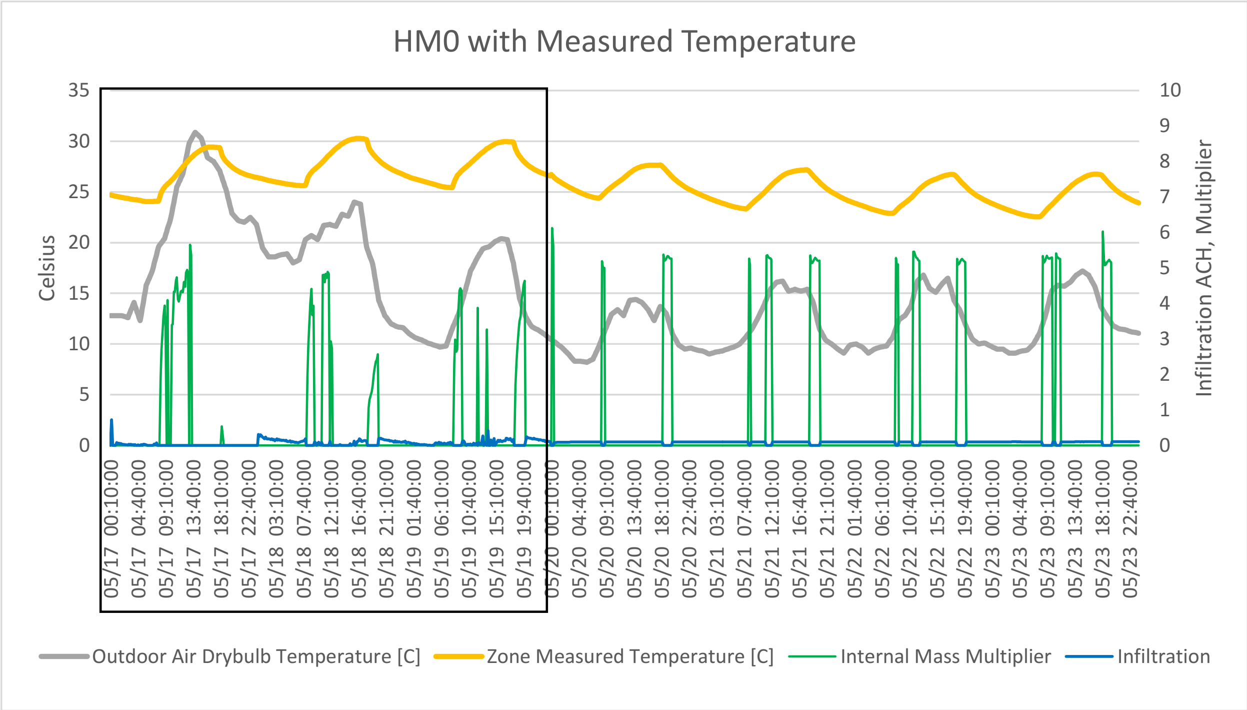

Figure 24 The Calculated Infiltration and Internal Mass Multiplier for the HM0 Experiment Case using the Measured Zone Air Temperature

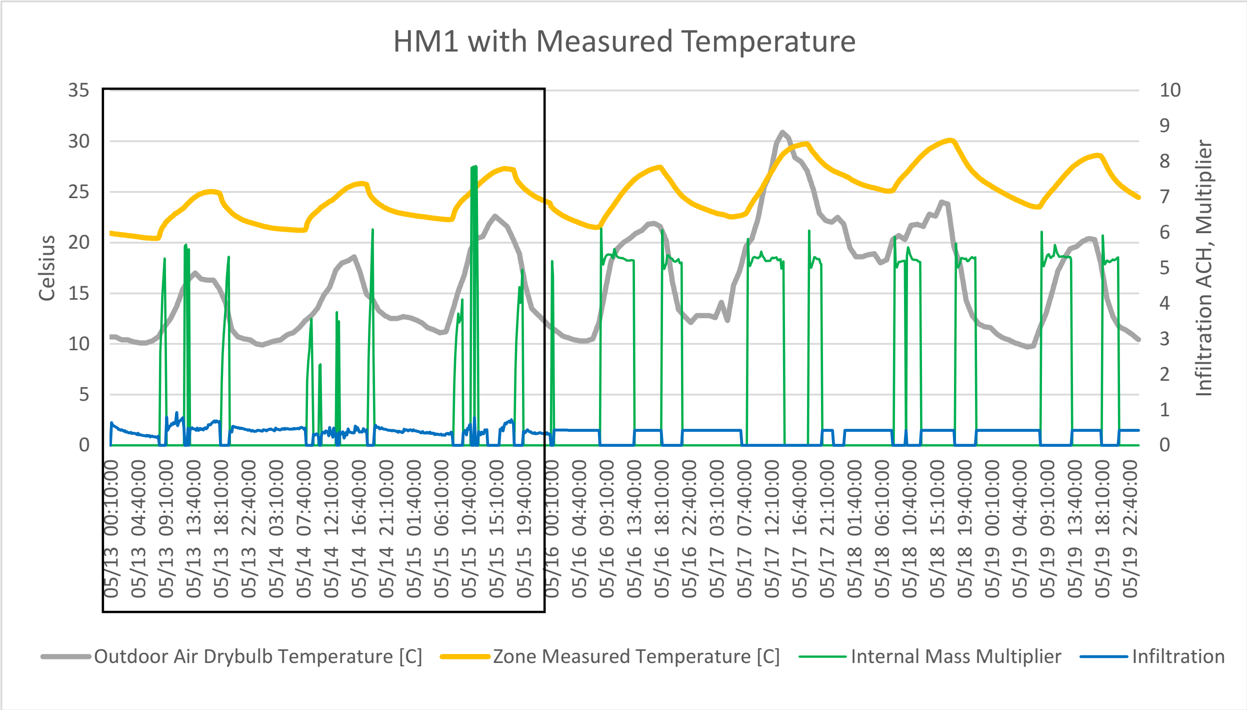

Figure 25 The Calculated Infiltration and Internal Mass Multiplier for the HM1 Experiment Case using the Measured Zone Air Temperature

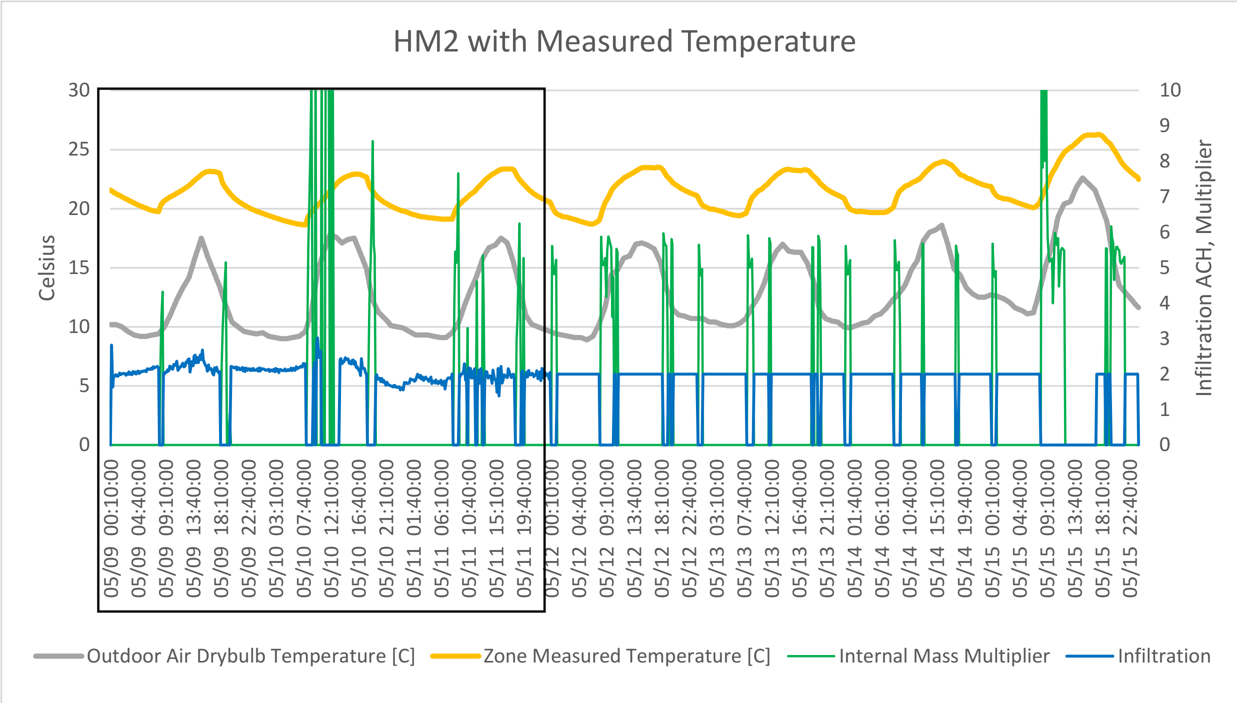

Figure 26 The Calculated Infiltration and Internal Mass Multiplier for the HM2 Experiment Case using the Measured Zone Air Temperature

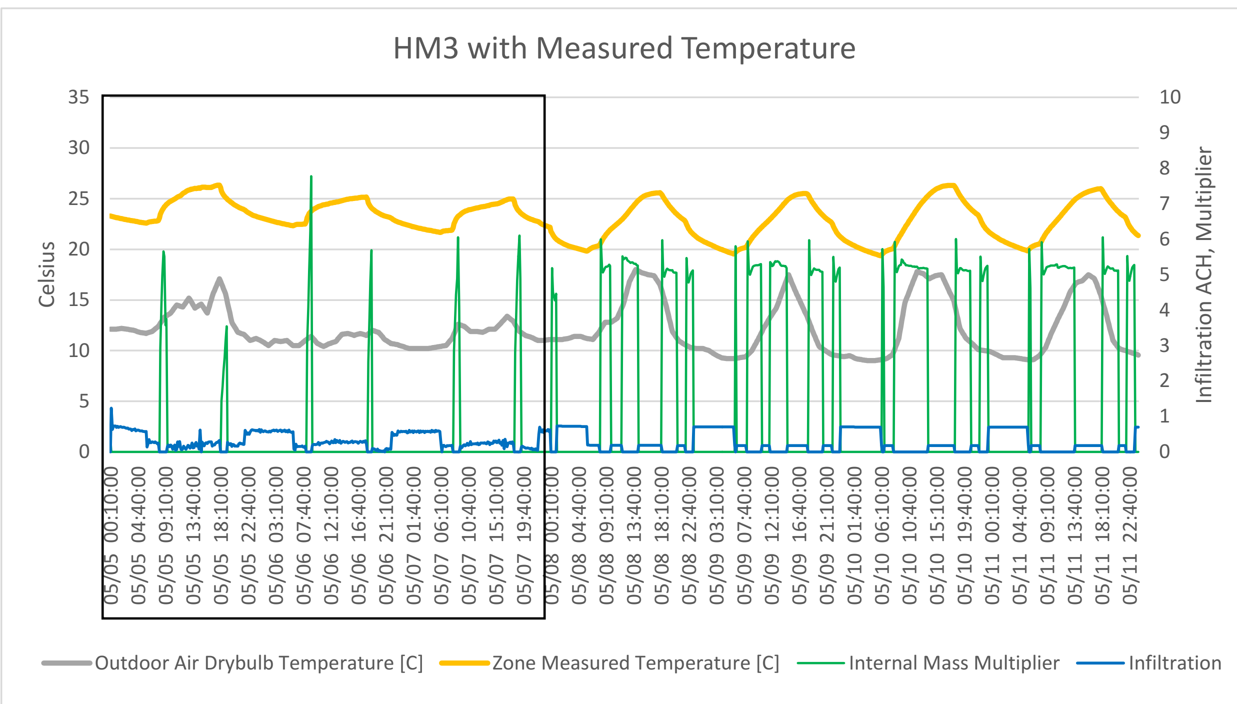

Figure 27 The Calculated Infiltration and Internal Mass Multiplier for the HM3 Experiment Case using the Measured Zone Air Temperature

5 Guideline and Discussion of using the Hybrid Modeling

The validation using the FLEXLAB experiment data enlightened us about a guideline to use the hybrid modeling simulation implemented in EnergyPlus. Major findings are:

1. Thermal mass is an important component for building performance as it stabilizes internal temperatures, thus certain period of the measured zone air temperature is needed to capture the thermal inertia of the building structure and interior furniture/mass. It is recommended to run a test for one week (seven days) to have adequate measurement of the zone air temperature. The temperature data interval works the best with ten minutes to meet the recommended resolution of the EnergyPlus simulation timesteps of ten minutes.

2. Filters need to be applied for more reliable inverse calculation to avoid the anomaly conditions due to the use of the inverse zone heat balance equation (details in the new feature proposal for EnergyPlus), when the timesteps meet the following conditions:

   Infiltration calculation is only done when:

$$\left|T_{zoneair\_i} - T_{outdoor_i}\right| > 5\ °C \text{ and } \left|T_{zoneair_i} - T_{zoneair_i - 1}\right| < 0.1°C$$

   IM multiplier calculation is only done when:

$$\left|T_{zoneair\_i} - T_{zoneair_i - 1}\right| > 0.1°C$$

   Where

   $T_{zoneair\_i}$ Zone air temperature at the current time step
   $T_{zoneair\_i-1}$ Zone air temperature at the previous time step
   $T_{outdoor\_i}$ Outdoor air temperature at the current time step.

3. The challenge of the hybrid model algorithm lies when both infiltration and internal mass parameters are unknown. We conducted a sensitivity study of the infiltration and IM multipliers using the calibrated model and the measured temperature data.
4. shows the calculated infiltration rate with various IM multiplier inputs. Values are averaged from the seven days of the simulated and measured temperature data (as explained in Section 4.2). Based on the sensitivity study, the infiltration parameter is less sensitive than the IM multipliers.

Table 7 The Calculated Infiltration with Different IM Multiplier Inputs.

				IM Multiplier Input						
				3	5	7	9	11	13	15
LM0	Infiltration Original Input with	0.10	Infiltration ach back calculated using hybrid modeling algorithms with different IM multipliers	0.11	0.11	0.14	0.17	0.20	0.23	0.26
LM1		0.42		0.42	0.43	0.45	0.47	0.49	0.55	0.56
LM2		2.00		1.97	2.01	2.05	2.09	2.13	2.11	2.21
HM0		0.10		0.10	0.10	0.11	0.15	0.18	0.22	0.25
HM1		0.42		0.43	0.42	0.42	0.43	0.46	0.50	0.55
HM2		2.00		2.03	2.02	2.02	2.02	2.02	2.02	2.02

This provides a guideline for the sequence of the hybrid model simulation when both infiltration and IM multiplier are unknown. The infiltration hybrid model simulation comes first. This requires the assumption of a default IM multiplier that can represent a typical office furnishing configuration. From previous validation study using the DOE reference models, the IM multiplier of 8 reflects a typical office internal mass environment. It is recommended to use an IM multiplier of 3 to 6 for light offices, 6 – 10 for typical offices, and 10 – 15 for heavy mass office configurations.

For the use of hybrid model when internal mass and infiltration inputs cannot be estimated, the default input of the IM multiplier of 8 is used to derive infiltration air flow rate. For the infiltration mode of the hybrid model simulation, the calculation is only done when the zone air temperature difference between the current and previous timestep is less than 0.1°C.

Based on the validation and the sensitivity study, the base thermal mass multiplier of 8 provided good estimate of the infiltration. However, the initial IM input of 8 does not capture the real IM conditions. Once the hybrid simulation for the infiltration mode is done, the derived infiltration is used as the input to the hybrid simulation for running in the internal mass mode to correct the IM multiplier. For this, the applied filter, zone air temperature difference smaller than 0.1°C is used to exclude the IM calculation results for those timesteps. Thus the derived IM multiplier is not the same as the base input multiplier, 8. This newly calculated multiplier represents the real internal mass configuration. Detailed simulation process using the hybrid model in EnergyPlus is described in the new feature proposal (as well as in the EnergyPlus Input Output Reference Manual).

5. The accuracy of the hybrid model simulation is greatly dependent of the completeness of the energy model. The infiltration air flow rate and IM multipliers are inversely derived using the energy model with the input of measured air temperature data. Thus, other uncertain parameters will have impacts on the infiltration and IM multipliers, because there are multiple combinations of the parameter values that can meet the environmental condition of the measured zone air temperature. The accurate actual weather data is also needed for the period of the hybrid model simulation. Future research is needed to investigate how the hybrid modeling can be integrated with traditional model calibration process to improve accuracy of simulation.

6. The current implementation of hybrid modeling applies to periods when HVAC systems are off, i.e. spaces are in free floating mode. However, this is not a limitation of the hybrid modeling but rather based on the assumption that measured energy delivered by HVAC systems is not easily available. When the measured energy at timestep from the HVAC systems (delivered energy or supply airflow and temperature) is known, the hybrid model applies.

6 Summary

This report summarizes the FLEXLAB experiment designed to collect zone air temperature data under eight controlled testing configurations. The testing environment include two internal mass configurations and four infiltration air flow rate configurations. The measured zone air temperature was used for the validation of the hybrid model. The hybrid model, implemented in a custom branch of EnergyPlus 8.3, was used to inversely calculate the zone internal thermal mass and zone air infiltration rate. The detailed validation of the hybrid model simulation results were provided for each test case, showing good agreements between the simulated results from the hybrid model and the measured data from the FLEXLAB experiments. Lessons and insights learned from the validation using the FLEXLAB experiment data were used to refine the hybrid modeling algorithm and to provide a guideline on the use of the hybrid model in EnergyPlus.

7 References

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